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Machine learning optimization of supercontinuum properties towards multiphoton microscopy

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Abstract: We implement machine learning to optimize spectro-temporal properties of supercontinuum generation during nonlinear fiber propagation. In particular, we numerically study how the suitable adjustment of femtosecond pulse patterns can be leveraged to maximize the output spectral intensities and temporal waveforms at wavelengths relevant for multi-photon imaging.

Multi-photon excitation (MPE) microscopy has played a significant role in biological imaging techniques since it allows to observe living tissues with further depth and excellent sectioning effect. MPE microscopy relies on multi-photon absorption (MPA), enabling the use of different imaging modalities that strongly depends on the properties of both the selected fluorophore and the laser excitation (e.g., wavelength, pulse duration, peak power) [1]. However, versatile and tunable laser excitation for MPA is still a challenge. As an alternative, supercontinuum (SC) generation can be implemented for multi-photon imaging, as it can provide broadband excitation covering numerous fluorophore MPA peaks and potentially enables easier multiplexed spectroscopy [2].

Here, we report on the use machine learning to optimize the spectro-temporal properties of SC generation to selectively enhance MPE signals compatible with a variety of fluorophores and excitation modalities for MPE microscopy. Specifically, we numerically explore how the use of reconfigurable (femtosecond) pulse patterns can be readily leveraged to suitably control the propagation dynamics in a highly-nonlinear fiber (HNLF) [3], so that to maximize typical MPA excitations at selected wavelengths, and in a versatile manner for imaging.

In our simulations, we consider multiple-pulse pattern excitation whose tunable generation and shaping was previously reported from on-chip cascaded Mach-Zehnder interferometers (MZIs) [3,4], yielding up to 256 pulses with 1 ps separation. After HNLF propagation, the output spectrum is filtered at selected wavelengths and machine learning techniques, in particular a genetic algorithm (GA), is used to iteratively maximize the MPA.

In this example, we selected two particular wavelengths (1133 and 1700 nm) that can be respectively used for two-photon absorption (2PA) and three-photon absorption (3PA). Taking advantage of machine learning optimization, we can efficiently probe the input parameter space and rapidly enhance the desired MPE signal.

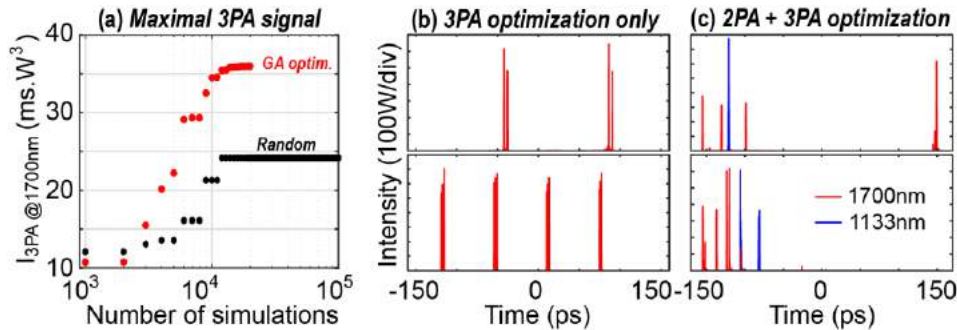


Figure 1 : (a) Evolution of maximal 3PA signal at 1700 nm obtained from Monte-Carlo simulations or via GA optimization. Example of temporal waveforms obtained after spectral filtering for (b) 3PA optimization or (c) conjoint 2PA + 3PA optimization

Besides MPA signal optimization, the use of reconfigurable input pulse patterns allows for versatile adjustment of the temporal output profile at selected wavelengths and additional SC simulations also show the ability to successfully enhance MPE signals for different combinations of fluorophores and/or modalities.

Altogether, we expect this approach to mitigate time-consuming adjustments and ensure efficiency in versatile experimental optimization for MPE microscopy. In particular, we anticipate that this flexibility in terms of pulse shaping will allow for tailoring the intensities and delays of 2PA and 3PA signals and pave the way towards further MPE microscopy improvements in terms of spatial sectioning, optical toxicity and wavelength selectivity.

References

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